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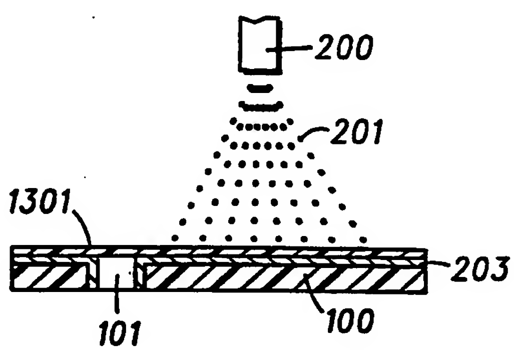
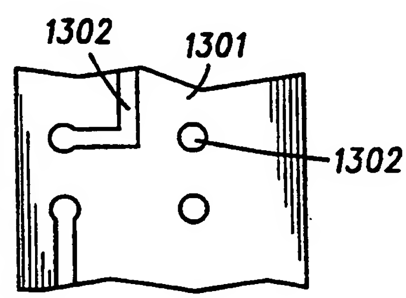
(54) Title: METHOD FOR FORMING CIRCUITRY BY A SPRAYING PROCESS WITH STENCIL





(57) Abstract

A printed circuit device includes a non-conductive substrate (100) having conductive metallic circuit paths (203) bonded, by thermal spraying through a stencil (1301), on at least one surface thereof. In one embodiment, both sides of the substrate (100) are so treated. In another embodiment, a second layer of conductive material (301), such as tin, is also thermal sprayed over the first conductive layer. This technique of thermal spraying through a stencil readily accommodate three dimensional surface contours as occur when using molded circuit boards.

METHOD FOR FORMING CIRCUITRY BY A SPRAYING PROCESS WITH STENCIL

METHOD FOR FORMING CIRCUITRY BY A STENCIL PROCESS AND RESULTING APPARATUS

Field of the Invention

This invention relates generally to printed circuit board technology.

Background of the Invention

Printed circuit boards are well understood in the art. To form such a board, sheet stock of non-conductive material (such as FR-4 plastic) has a conductive layer (such as copper) bound thereto. Using a masking technique, an etch resistant chemical is disposed on the conductive layer in a shape corresponding to a desired electrical circuit. The resultant board is then placed in a chemical bath that removes all conductive material that had not been so chemically treated.

A circuit board resulting from the above described process, while satisfactory for many applications, is not without certain drawbacks. For example, the copper pattern can be removed from the substrate by various physical forces (including adhesive forces) thereby ruining the circuit. Consequently, care must be taken that the conductive paths formed on the resulting circuit board are not so narrow as to unduly challenge the durability of the copper bond itself. Another problem involves cost. The copper bonding process itself will only function reliably with certain plastic materials. As a result, other plastics costing less will not yield a

satisfactory circuit board when using these prior art fabrication techniques.

Molded circuit boards are also known in the art. Here, the non-conductive substrate, rather than being sheet stock, comprises plastic as molded into a desired shape. Although the desired shape can be planar like sheet stock circuit boards, a molded circuit board can also have three dimensional features (for example, a pin-out connector can conveniently be molded as part of the board itself). By using the same etching processes as described above, conductive paths (including conductive paths that conform to the three dimensional features) can be applied to the board.

In addition to being able to mold circuit boards having three dimensional features, this approach has the additional advantage of allowing use of less expensive plastic material. This otherwise desirable alternative, however, suffers from at least one particularly significant drawback; copper must be bonded to the substrate in the first instance through use of a chemical electroplating process. Chemical electroplating suffers from a variety of problems. The process requires many hours to prepare a board before the resist and etching processes can occur. This process also requires a significant amount of space in a fabrication facility (yards and yards of tanks of various chemicals are usually required). The process is relatively inefficient, since only 75% of available copper is eventually applied to the board or otherwise utilized in some useful manner; the rest is lost as waste. And finally, the process is environmentally questionable. A wide variety of liquid chemicals are required in the process, and these chemicals all require proper handling prior to use, during use, and after use. Many legal jurisdictions are seriously considering an outright ban on such

electroplating processes because of these environmental concerns.

Available printed circuit board manufacturing methodologies thereby give rise to a variety of needs. In particular, a plating process that will allow use of less expensive substrate materials, ensure a higher integrity copper bond to the substrate, and that will allow use of molded circuit boards is highly desired. Circuit boards of one type or another are used in virtually all electronic products, and the potential cost and quality advantages to be gained by such an advance are enormous. In addition, a process that allows extremely selective deposition of conductive material on a substrate would eliminate subsequent photo-resist and etch processes, thus decreasing both cost and cycle time.

Summary of the Invention

These needs and others are substantially met through provision of the disclosed method of forming a printed circuit device. Pursuant to this method, a substrate comprised of non-metallic material has a stencil affixed thereto, with the stencil having openings corresponding to a desired circuitry pattern. Metallic conductive material is then sprayed on the stencil such that the metallic conductive material reaches the substrate through the openings. Subsequently, the stencil is removed, leaving the desired circuitry pattern on the substrate.

In one embodiment of the invention, the spraying is achieved through use of a thermal spraying method.

In various embodiments, stencils can be affixed to one or both sides of a substantially planar substrate, or to one or many sides of a three dimensional substrate as provided through use of a molded substrate.

Brief Description of the Drawings

FIG. 1 comprises a side elevational, sectioned view of a substrate;

FIG. 2 comprises a side elevational, sectioned view of the substrate having a conductive material sprayed thereon;

FIG. 3 comprises a side elevational, sectioned view of a second metallic conductor being sprayed toward the substrate;

FIG. 4 comprises a top plan, detailed view of a resulting circuit pattern;

FIG. 5 comprises a side elevational view of an alternative embodiment;

FIG. 6 comprises a side elevational, sectioned view of another alternative embodiment;

FIG. 7 comprises a side elevational view of another alternative embodiment in a subsequent processing step;

FIG. 8 comprises a perspective detailed view of another embodiment;

FIG. 9 comprises a side elevational view of yet another embodiment;

FIG. 10 comprises a side elevational, sectioned view of yet another alternative embodiment;

FIG. 11 comprises a top plan view of the alternative embodiment depicted in FIG. 10;

FIG. 12 comprises a block diagram of a radio; and

FIG. 13 illustrates a typical stencil.

Description of a Preferred Embodiment

To begin the process, a substrate (100) (FIG. 1) comprised of non-metallic material is provided. This substrate (100) may be comprised of, for example, sheet

stock, such as FR-4 or CEM plastic, or the substrate (100) can comprise a molded substrate, in which case the material could be, for example, Hoechst Celenese-Fortron (PPS-resin) or even Amoco-Amodel (PPA-resin). (The applicant has determined that other substances, including ceramic and mica, also work well in this application.) As appropriate to a particular application, the substrate (100) can have one or more holes (101) formed therethrough in accordance with well understood printed circuit board techniques.

A stencil (1301) is then affixed to the substrate (100). The stencil (1301), as shown in FIG. 13, is comprised of a relatively thin sheet of plastic (or other material impervious to thermal-sprayed metal). The stencil (1301) has material selectively removed from it to correspond to a desired circuit pattern (1302). The stencil (1301) is affixed to the substrate (100) with an adhesive. Locator pins on the substrate may be designed to mate with corresponding openings in the stencil to ensure precise placement.

Next, using a thermal spray gun (200) (FIG. 2) (such as a DJ Diamond Jet gun as manufactured by Metco Perkin Elmer), a metallic conductive material is thermal (flame) sprayed (201) on to the stencil (1301), reaching the substrate through the openings in the stencil to provide metallic circuit paths (203) in the desired pattern on the substrate (100). In this particular embodiment, the metallic conductive material comprises copper (in a preferred embodiment, this copper is at least 98.5% pure).

This flame spraying technique constitutes a process where a copper powder is melted in a mixture with oxygen, propylene, and air. This molten copper (having a temperature of between 1,649 degrees C and 1,927 degrees C) is then propelled from the thermal

spray gun (200) at a velocity of 762 to 914 meters per second onto the substrate (100). Typically, the spray gun (200) is positioned between 25.4 and 50.8 centimeters from the substrate (100) during this process. The length of time the gun (200) is maintained in any one position depends upon how much copper build-up is needed in any given area. This process creates a mechanical bond between the copper and substrate that is virtually inseparable in the absence of chemical etching.

The above thermal spraying process has numerous significant advantages over the prior art techniques. For example, the bond between the copper and the substrate is considerably stronger than that attained by normal prior art methodology. Also, the process is more efficient; with available unused-material recovery systems known to those skilled in the art of thermal spraying, more than 99% of the available copper is ultimately utilized for plating purposes (as compared to the 25% waste that typifies chemical electroplating). Further, instead of requiring many hours as in chemical electroplating, a typical circuit board can be completely plated in only a few minutes (for example, a 10 cm x 13 cm board requires only about 90 seconds).

Other advantages exist as well. The spray booth requires much less space than does the counterpart equipment in a chemical electroplating process. Also, no dangerous liquid chemicals are required, and hence the process constitutes a significantly more environmentally friendly one. Further, the applicant has determined that this process works successfully with a variety of plastic materials, including significantly less expensive moldable plastic materials. As a result, the cost of the substrate itself can be reduced by as much as 50% to 75% or more as compared to typical prior art sheet stock materials. Lastly, the applicant has

determined that the process will also provide a satisfactory conductive coating on the interior walls of holes (101) formed through the substrate (100), a feature often required when constructing a printed circuit device.

If desired, a second flame spray step can be included (FIG. 3) to allow a second layer (301) of metallic conductive material (such as 90% pure tin) to be deposited over the first layer (203). By providing for this step, the copper can also be tinned in a convenient, efficient, rapid, environmentally friendly manner.

Following either the copper plating step, or the tin deposition step (depending upon the needs of a particular application), the stencil is removed from the substrate leaving the desired circuit pattern (FIG. 4). If desired, metallic overspray on the stencil may be recovered, thus reducing waste.

Because of the high integrity of the bond between the conductive material and the substrate (100), the conductive patterns (401, 402, and 404) can be made quite narrow if desired. Such may be desired when current handling requirements are low and space on a circuit board is at a premium. By way of comparison, using the present technique, conductive paths that are at least half the width of conductive paths that are safely obtainable with present day techniques can be readily provided.

Using the basic steps outlined above, a variety of alternative embodiments for printed circuit devices are available. For example, both sides of a substantially planar substrate (100) (FIG. 5) can have stencils attached and then be thermally treated as above to provide for a copper circuitry layer (203 and 500) and a tin layer (301 and 501) on both sides of the substrate (100). To accomplish this, the substrate (100) need only

be reversed following thermal spraying of the first side to allow thermal spraying of the second side. In the alternative, opposing spray guns can be utilized to accomplish simultaneous spraying of both sides. So configured, a two-sided circuit board having a two dimensional circuit pattern formed on each side thereof can be attained.

In another embodiment, the thermal spraying process for the copper material (203) (FIG. 6) can be selectively controlled to provide for a greater deposition of material at some locations on the substrate (100) than on others. Such an increased deposition appears in FIG. 6 as denoted by reference numeral 600. This may be desired, for example, when imparting a particular desired thermal performance characteristic to a printed circuit device. Following removal of the stencil (FIG. 7), this area of increased thickness of conductive material (600) could serve, for example, as a small heat sink for a corresponding circuit component that is mounted thereon. Similarly, such an area of increased thickness could be utilized to handle circuit needs where current densities would be higher than in other areas of the circuit.

As noted earlier, molded circuit devices allow three dimensional features to be introduced into the device. In FIG. 8, an illustrative three dimensional figure comprises a four sided box (800) integrally formed, via the molding process, with the substrate (100). Using the thermal spraying process described above, the exterior surfaces of this substrate (100), including the three dimensional feature (800), will have a conductive layer bonded thereto. Relatively thin plastic stencils can be designed to conform easily to irregular substrate features. When the stencils are removed, conductive circuit patterns (801 and 802) are

left that conform to the surface characteristics of the substrate (100), including the three dimensional feature (800) itself, thereby yielding a three dimensional circuit pattern on one side of the substrate (100).

With reference to FIG. 9, a particular substrate (100) may have three dimensional features on more than one side thereof. For example, a four sided box may appear on both sides of an otherwise substantially planar substrate (100). Through use of thermal spraying of both sides of the substrate (100), and again after stencil removal, three dimensional circuit patterns (801 and 901) can be readily deposited on both sides of the substrate (100) in conformance with the contours of the three dimensional features themselves.

The above described process can also be used to fabricate multi-layer circuit devices. Referring to both FIGs. 10 and 11, the circuit patterns (1000 and 1001) that comprise the first circuit layer in this example are formed as described above by thermal spraying copper (203) onto a substrate (100). Next, an insulating layer (1002) (comprised of any appropriate insulating material) is applied over the first circuit layer. Such an insulating layer can be applied through use of prior art techniques whereby such insulating layers are created in prior art multi-layer circuit boards. Then, the thermal spraying process can again be used to apply copper circuitry patterns on the insulating layer (1002), following which stencil removal leaves the circuit pattern (1003) that comprises the second circuit layer in this example. This procedure can of course be repeated to create yet additional circuit layers. Also, the final layer can be tinned as described above.

The printed circuit devices that result from the above described process have a wide variety of industrial applicability. For example, consider an

existing two-way radio (1200) (FIG. 12). By taking the existing printed circuit boards in a typical two-way radio (1200) and replacing the sheet stock printed circuit boards with identically featured molded printed circuit boards that have been plated using the above described processes, the cost of the printed circuit board substrates can be readily reduced by 25% to 75%. At the same time, the quality of the boards increases significantly. Further, since this process accommodates molded circuit devices so well, the existing radio (1200) can likely be readily redesigned, from a physical standpoint, to substantially benefit from various three dimensional features that can be readily introduced through use of a molded printed circuit device. As a result, the same radio can likely be made even smaller and less expensive.

The use of thermal spraying to accomplish electroplating with a non-conductive substrate presents significant benefits and freedoms to printed circuit device designers. Significant cost savings, space savings, and freedom of design is significantly enhanced. Concurrent with these gains, the process imposes considerably less stress on the environment.

What is claimed is:

Claims

1. A method for forming a printed circuit device, comprising the steps of:

A) providing a substrate comprised of non-metallic material;

B) affixing a stencil to the substrate, the stencil having openings therethrough corresponding to a desired circuitry pattern;

C) thermal spraying a metallic conductive material on the stencil, such that the metallic conductive material reaches the substrate through the openings in the stencil;

D) removing the stencil from the substrate.

2. The method of claim 1, wherein the step of thermal spraying includes the steps of:

B1) thermal spraying a first metallic conductive material on the stencil;

B2) thermal spraying a second metallic conductive material on the first metallic conductive material.

3. The method of claim 2, wherein the first metallic conductive material comprises copper, and the second metallic conductive material comprises tin.

4. The method of claim 3, wherein the first metallic conductive material is at least 98.5% copper, and the second metallic conductive material is at least 90% tin.

5. The method of claim 1, wherein the step of removing the stencil leaves a two-dimensional circuit pattern on the substrate.

6. The method of claim 1, wherein stencils are applied to at least two sides of the substrate, and the step of removing the stencils leaves a two-dimensional circuit pattern on said at least two sides.

7. The method of claim 1, wherein the step of removing the stencil leaves a three-dimensional circuit pattern.

8. The method of claim 1, wherein stencils are applied to at least two sides of the substrate, and the step of removing the stencils leaves a three-dimensional circuit pattern on said at least two sides.

9. The method of claim 1, wherein the step of thermal spraying deposits the metallic conductive material in selectively variable thicknesses in selected locations on the substrate.

10. The method of claim 9, wherein the step of removing the stencil forms a circuit pattern having conductive portions formed of the metallic conductive material, wherein at least some of the portions have thicknesses that selectively differ from one another.

FIG.1

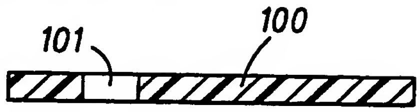


FIG.2

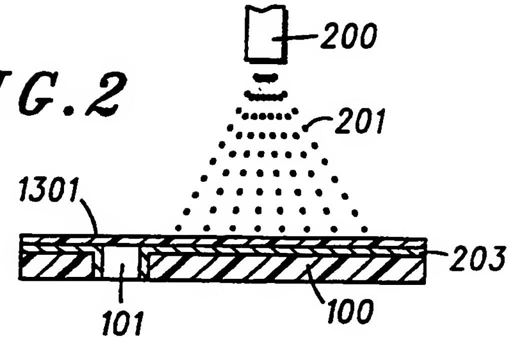


FIG.3

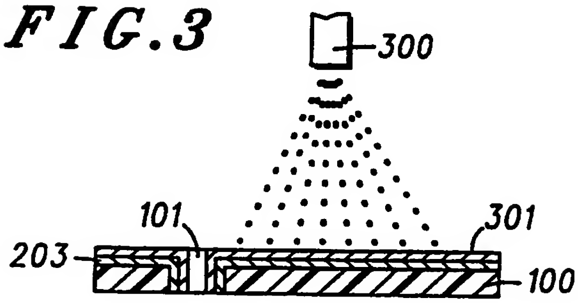


FIG.4

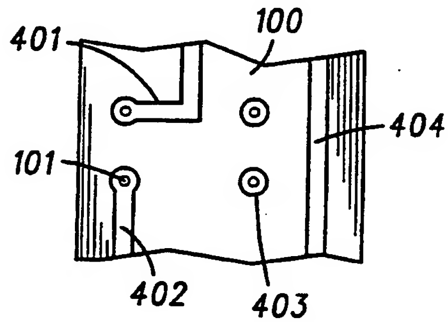


FIG.5

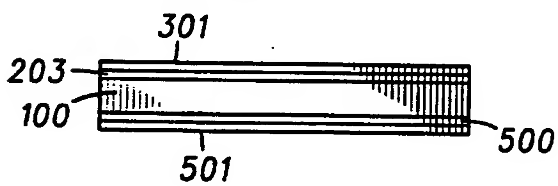


FIG.6

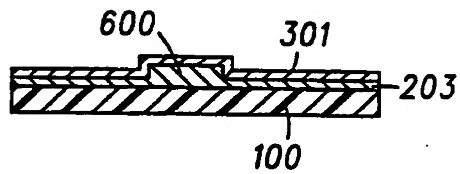


FIG.7

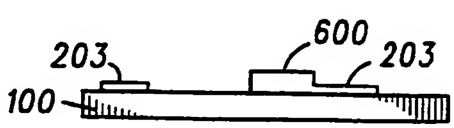


FIG. 8

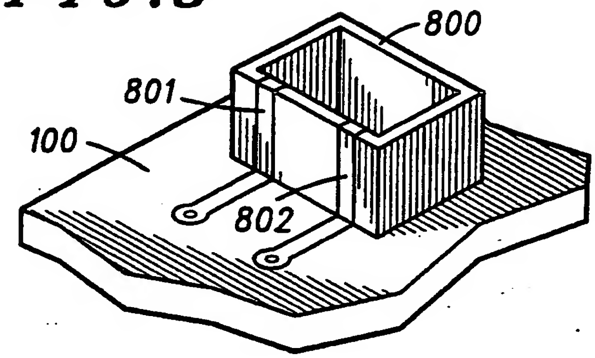


FIG. 9

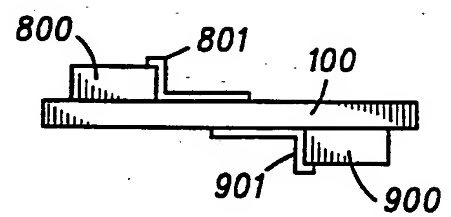


FIG. 10

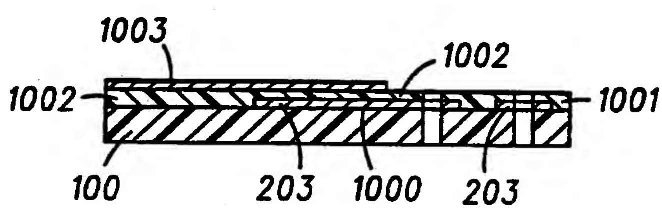


FIG. 11

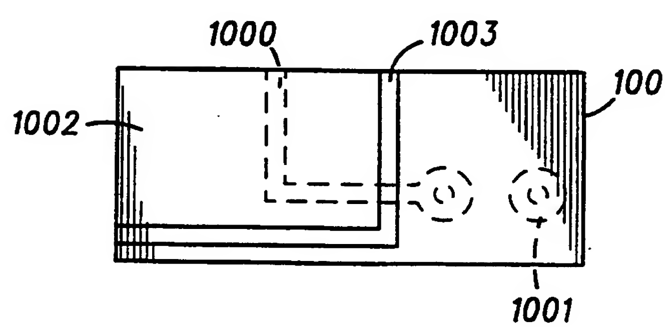


FIG. 13

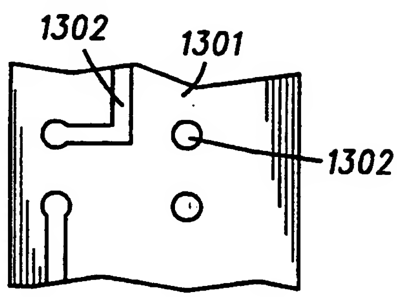
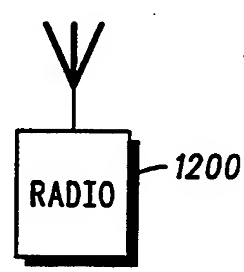


FIG. 12



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/08749

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :B05D 1/00;C23C 4/00
US CL :427/448
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 427/96, 97, 282, 455, 448

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A, 4,263,341 (Martyniak) 21 April 1981, see col. 2, lines 26-27, 29-34; col. 4, line 43; col. 7, line 24.	1-8
Y	US,A, 4,940,623 (Bosna et al) 10 July 1990, see col. 1, lines 9-10; col. 2, lines 43-44; col. 4, lines 5-6, 9-10.	6-8
Y	National Bureau of Standards Circular 468, 15 November 1947, Cledo Brunetti et al, Printed circuit Techniques, pages 21-22.	4
A	US,A, 3,607,381 (Fairbairn) 21 September 1971.	

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search	Date of mailing of the international search report
15 NOVEMBER 1993	16 DEC 1993

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